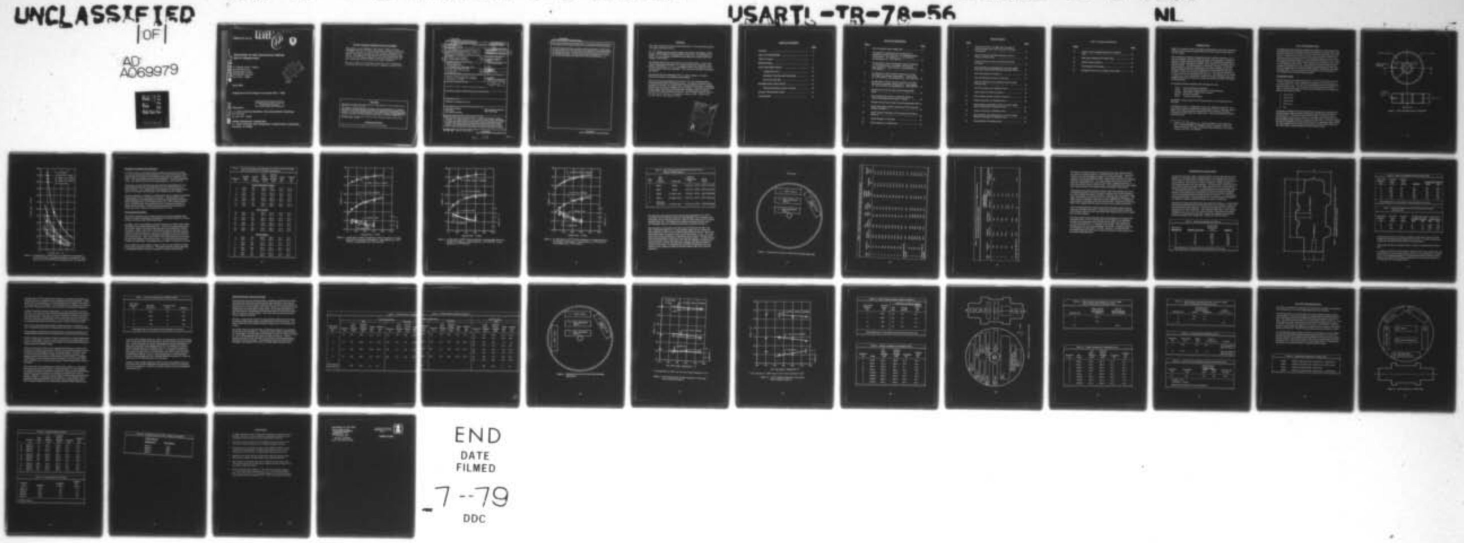
AD-A069 979 GENERAL ELECTRIC CO LYNN MA AIRCRAFT ENGINE GROUP F/G 21/5
DEVELOPMENT OF HOT ISOSTATICALLY PRESSED RENE 95 TURBINE PARTS.--ETC(U)
APR 79 P S MATHUR, J L BARTOS DAAJ02-73-C-0106
UNCLASSIFIED USARTL-TR-78-56 NL

1 OF 1
AD
A069979



END
DATE
FILMED
7--79
DDC

LEVEL III A043688

USARTL-TR-78-56

AD A069979

DEVELOPMENT OF HOT ISOSTATICALLY PRESSED RENÉ 95 TURBINE PARTS

P. S. Mathur and J. L. Bartos
General Electric Co.
Aircraft Engine Group
1000 Western Avenue
Lynn, Mass. 63166

April 1979

Supplemental Final Report for Period 1976 - 1978

Approved for public release;
distribution unlimited.

Prepared for

U. S. ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
P.O. Box 209
St. Louis, Mo. 63166

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report, as an addendum to the contract Phase II report (USAAMRDL-TR-76-30), provides supplemental information regarding the proper selection of critical heat treatment parameters for powder metallurgy processing and the resulting mechanical properties. The results of this effort have been incorporated into the current T700 engine hardware production specifications and have contributed to other efforts and engine programs.

Mr. Jan M. Lane of the Propulsion Technical Area, Aeronautical Technology Division, served as project engineer for this effort.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
18 USARTL-TR-78-56

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
6 DEVELOPMENT OF HOT ISOSTATICALLY PRESSED RENÉ 95 TURBINE PARTS. Addendum.

5. TYPE OF REPORT & PERIOD COVERED
~~Supplemental~~ Final rept. 1976 - 1978 on Phase 2,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 P. S. Mathur [redacted] J. L. Bartos

8. CONTRACT OR GRANT NUMBER(s)
15 DAAJ02-73-C-0106
Phase II

9. PERFORMING ORGANIZATION NAME AND ADDRESS
General Electric Co.
Aircraft Engine Group
1000 Western Ave., Lynn, Mass. 01910

wst 403 389

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
1738046

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Aviation R&D Command
P. O. Box 209
St. Louis, MO 63166

12. REPORT DATE
11 Apr[redacted]979

13. NUMBER OF PAGES
42

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Applied Technology Laboratory, US Army
Research and Technology Labs (AVRADCOM)
Fort Eustis, VA 23604

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

12 43p.

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

A043 688

18. SUPPLEMENTARY NOTES

Addendum to USAAMRDL-TR-76-30

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hot Isostatic Pressing
Super Alloys
Gas Turbine Components
High Temperature Materials
Powder Metallurgy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report deals with the results of Task VI - Cooling Rate Analysis for Optimum Properties - of Contract DAAJ02-73-C-0106, Phase II, aimed at better understanding the critical heat treatment involved in the powder metallurgy production process for manufacturing premium quality hot isostatically pressed (As-HIP) René 95 engine hardware. The initial heat treatment study on test blocks and test specimens determined the effect of section size, quench media, and solution temperature on cooling

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403 389

rate from two different solution temperatures. The correlation between cooling rate microstructure and mechanical property was then established using test specimens.

The turbine disks heat treated with different solution temperatures, quench media, and with or without a bore hole defined the most desirable heat treatment parameters for achieving properties. The disks, first heat treated improperly but followed by the selected heat treatment, revealed that the double heat treatment may improve the mechanical properties of the disks initially heat treated improperly.

PREFACE

This report summarizes the work done under the U. S. Army Contract DAAJ02-73-C-0106, Phase II, Task VI.

Dr. P. S. Mathur was the program manager and principal investigator of this project. He provided overall supervision for this work. The responsible engineer, Dr. J. L. Bartos, contributed to the testing and evaluation and is the coauthor of this report.

The technical direction for the program was provided by Mr. J. Lane of the Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM). Dr. R. L. Dreshfield of NASA Lewis Research Center provided helpful and timely assistance. Their help and cooperation are greatly appreciated.

The guidance and encouragement of Mr. J. L. Hsia, Manager, Technical Resources Operation, are gratefully acknowledged.

This project was accomplished as part of the U. S. Army Aviation Systems Command Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel. Comments are solicited on the potential utilization of the information contained herein as applied to present and/or future production programs. Such comments should be sent to: U.S. Army Aviation Research and Development Command, ATTN: DRDAV-EXT, P. O. Box 209, St. Louis, Missouri 63166.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (CONTINUED)

INTRODUCTION

René 95 is a highly alloyed, precipitation-strengthened, nickel-base superalloy which is used to make two turbine disks and the four turbine cooling plates of the T700 engine.

The conventional method of manufacturing René 95 turbine hardware is comprised of forgings made from powder compacts or the cast ingot. Because of high alloy content, and thus the strength, René 95 is difficult and expensive to produce by these conventional methods, and the largest cost element is the forging cycle itself. The development of a successful, forgeless, hot isostatic pressing (HIP) process has a significant cost savings potential and can also develop properties comparable to forging with more homogeneity and reproducibility. This work, performed under the U. S. Army Contract DAAJ02-73-C-0106 (Phase II), was directed toward this goal. The objective was to develop a reliable, low-cost, reproducible, powder metallurgy production process for manufacturing premium quality hot isostatically pressed (As-HIP) T700 engine turbine hardware.

The program initially consisted of the following five tasks:

Task I	Process Refinement Definition
Task II	Fabrication and Evaluation of Lab Test Specimens
Task III	Fabrication of Engine Test Hardware
Task IV	Test and Evaluation
Task V	Technical Data Package

USAAMRDL Technical Report 76-30[1] describes the work completed in these five tasks.

An additional Task VI - Cooling Rate Analysis for Optimum Properties - was later added to define the fundamental relationships between cooling rate, quench media, and component section size needed to develop optimum mechanical properties in turbine disks and cooling plates. The work completed in Task VI is described here.

---

1. Mathur, P. S., and Bartos, J. L., DEVELOPMENT OF HOT ISOSTATICALLY PRESSED RENÉ 95 TURBINE PARTS, USAAMRDL-TR-76-30, Eustis Directorate, US Army Air Mobility R&D Laboratory, Fort Eustis, Virginia, May 1977, AD A043688.

HEAT TREATMENT STUDY

The fundamental heat treatment studies were conducted on test block and test specimen samples to determine the effect of section size, quench media, and solution temperature on cooling rate from the solution temperature in As-HIP René 95. Several levels of each parameter were evaluated by burying thermocouples at the mid-point of two sets of 6-inch-diameter by 1-inch, 2-inch, and 3-inch-thick plates (Figure 1). Data obtained in this study was to be used to construct curves from which cooling rates can be predicted in parts of one or more different section sizes. The correlation between cooling rate and mechanical properties was to be established by preparing tensile specimens and heat treating them in a vacuum facility capable of producing a wide range of cooling rates. Four cooling rates representative of those achievable in T700 hardware were applied to the specimens.

Cooling Rate Curves

One set of blanks was solution treated at T_S - 30^{O}F (2100^{O}F) where T_S is the γ' solvus temperature for 1 hour prior to quenching, while the second set was solutioned at T_S - 60^{O}F (2070^{O}F) to determine the effect of solution temperature on quench rate. All six blanks were solutioned and quenched five times to determine the effect of quench media and section size on quench rate. Quench media employed were:

1. Fan air cool.
2. 1200^{O}F salt.
3. 1000^{O}F salt.
4. 400^{O}F salt.
5. Oil.

Temperature readings from the embedded thermocouple were recorded at 15-second intervals using a portable potentiometer until the blank temperature reached 1200^{O}F. These data were analyzed to define cooling rate curves. The resulting curves, shown in Figure 2, represent actual cooling rates achieved in several quench media as a function of section size. The curves suggest that the 30^{O}F difference in solution temperature has a significant effect on cooling rates obtained from the slower quench media in small section sizes, but very little effect on rates obtained from faster quench media.

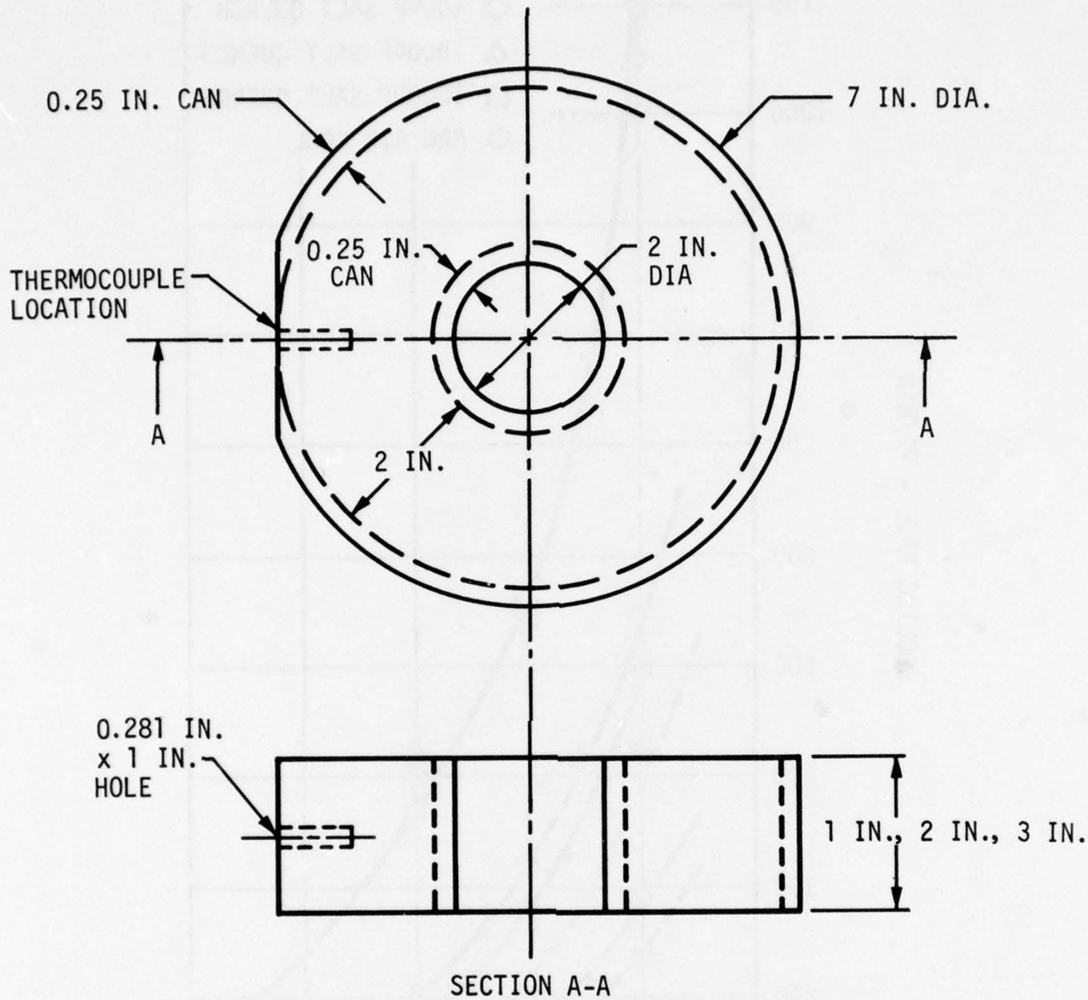


Figure 1. Heat Treat Study Blank Configuration

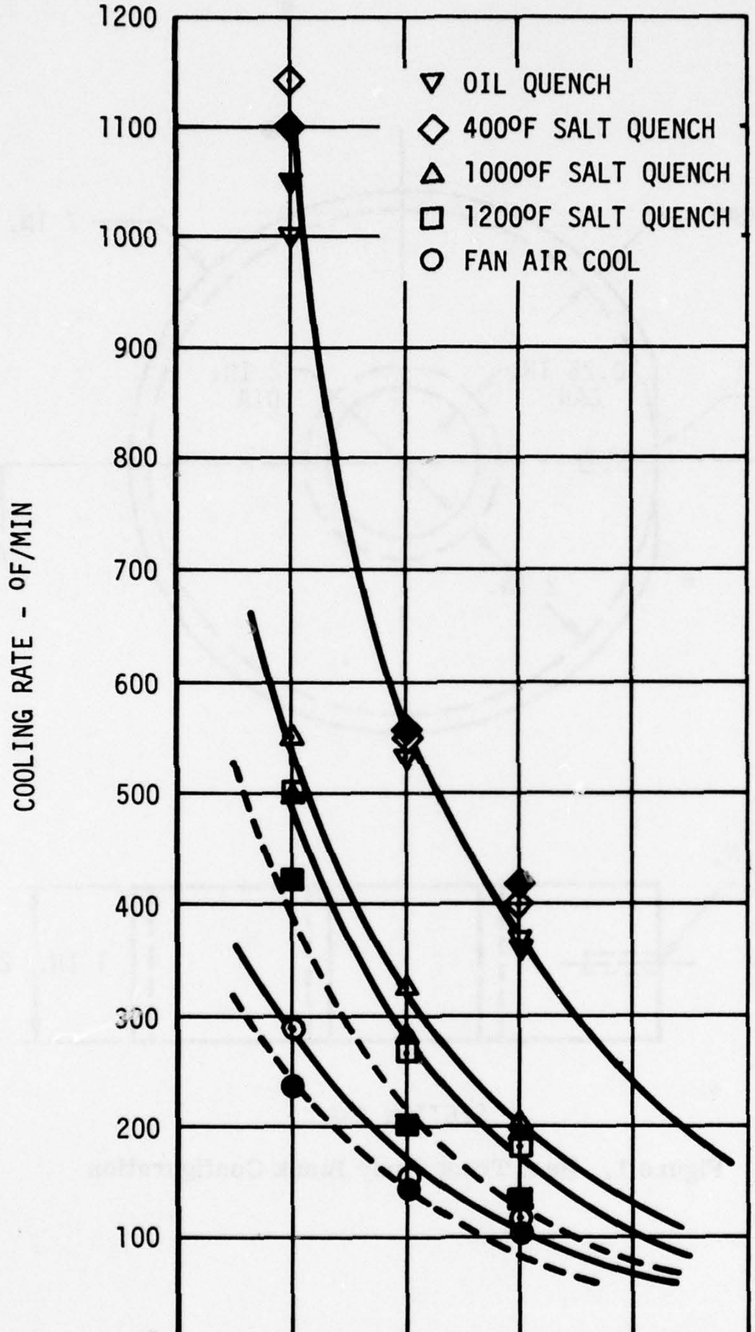


Figure 2. Cooling Rate vs. Section Size for As-HIP René 95 Quenched in Various Media from Two Different Solution Temperatures - Open Symbols T_S - 30°F (2100°F), Closed Symbols T_S - 60°F (2070°F)

Mechanical Properties and Cooling Rate

In order to obtain a relationship between mechanical properties and cooling rate, tensile specimens were machined from the cooling plate blanks to determine the effect of cooling rate and solution temperature on mechanical properties. Two sets of twelve specimens were prepared - one set for solutioning at T_S - 30°F (2100°F) and one set for solutioning at T_S - 60°F (2070°F).

Four groups of three specimens each (for three test temperatures) for each solution temperature were solutioned and cooled at a controlled rate in a vacuum furnace. Four cooling rates were examined for each solution temperature: 100°F/minute, 200°F/minute, 400°F/minute and 600°F/minute.

Tensile properties as a function of cooling rate for the two solution temperatures are presented in Table 1 and Figures 3 through 5. Results indicate only a slight degradation in yield strength at all three test temperatures and ultimate tensile strength (UTS) at 1200°F with the lower (T_S - 60°F) solution temperature. Ductilities were approximately the same, although some scatter in ductilities was observed. Overall tensile properties were consistent with Task I and Task IV results in Contract DAAJ02-73-C-0106.

Heat Treatment Evaluation

The tensile properties versus cooling rate data was used in conjunction with Figure 1 to define experimental heat treatment processing parameters as shown in Table 2 for five As-HIP T700 turbine disks.

The disks 1 and 2 were designed to examine the effects of a faster quench media and slightly lower solution temperature (T_S - 60°F) on the resultant properties. All the other aspects of the heat treatment practice were identical to Task III procedures. Disks 3 and 4 were to determine the effect of removing a portion of the bore slug on cooling rate. Only a 0.5-inch-diameter hole was employed to permit removal of a small metallographic and density sample from the bore after heat treatment. Disk 5 was to explore the benefits derived from removing the mild steel container from the bore area. This approach may increase the cooling rate significantly, with attendant improvements in mechanical properties.

The five disks were heat treated at Vendor A (Table 2) and evaluated according to the cut-up plan shown in Figure 6. The tensile and stress rupture test data is presented in Tables 3 and 4 and compared to average Task III results.

Table 1. Tensile Properties of As-HIP René 95 Cooled at Controlled Rates From 2070°F and 2100°F Solution Temperatures

Specimen No.	Solution Temp (°F)	Cooling Rate (°F/min)	% of Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)	Reduced Area (%)
			Room Temperature Tensile			
1	2100	100	165.1	228.7	19.4	21.4
3	2070	100	165.5	228.3	17.2	18.2
6	2100	200	172.8	232.6	17.5	20.3
8	2070	200	171.0	233.8	18.6	19.9
11	2100	450	184.5	236.6	13.1	14.5
13	2070	410	182.5	240.2	16.0	19.1
16	2100	600	189.3	242.9	14.2	15.9
18	2070	600	185.7	242.1	16.0	17.9
			800°F Tensile			
25	2100	100	155.3	213.8	18.3	18.8
5	2070	100	157.6	210.7	15.8	15.8
26	2100	200	164.4	217.8	15.7	16.2
10	2070	200	164.5	221.6	15.2	16.7
27	2100	450	174.2	223.3	11.7	12.1
15	2070	410	173.6	223.9	13.5	16.3
28	2100	600	179.3	225.4	11.9	13.1
20	2070	600	175.3	227.4	14.3	17.5
			1200°F Tensile			
2	2100	100	148.3	203.6	19.1	21.8
4	2070	100	150.9	203.7	17.5	18.3
7	2100	200	156.0	211.1	18.0	18.4
9	2070	200	157.3	208.4	14.5	17.0
12	2100	450	165.8	219.1	10.9	11.5
14	2070	410	167.7	216.2	12.7	14.8
17	2100	600	174.1	223.6	8.8	11.6
19	2070	600	168.3	219.8	10.8	12.3

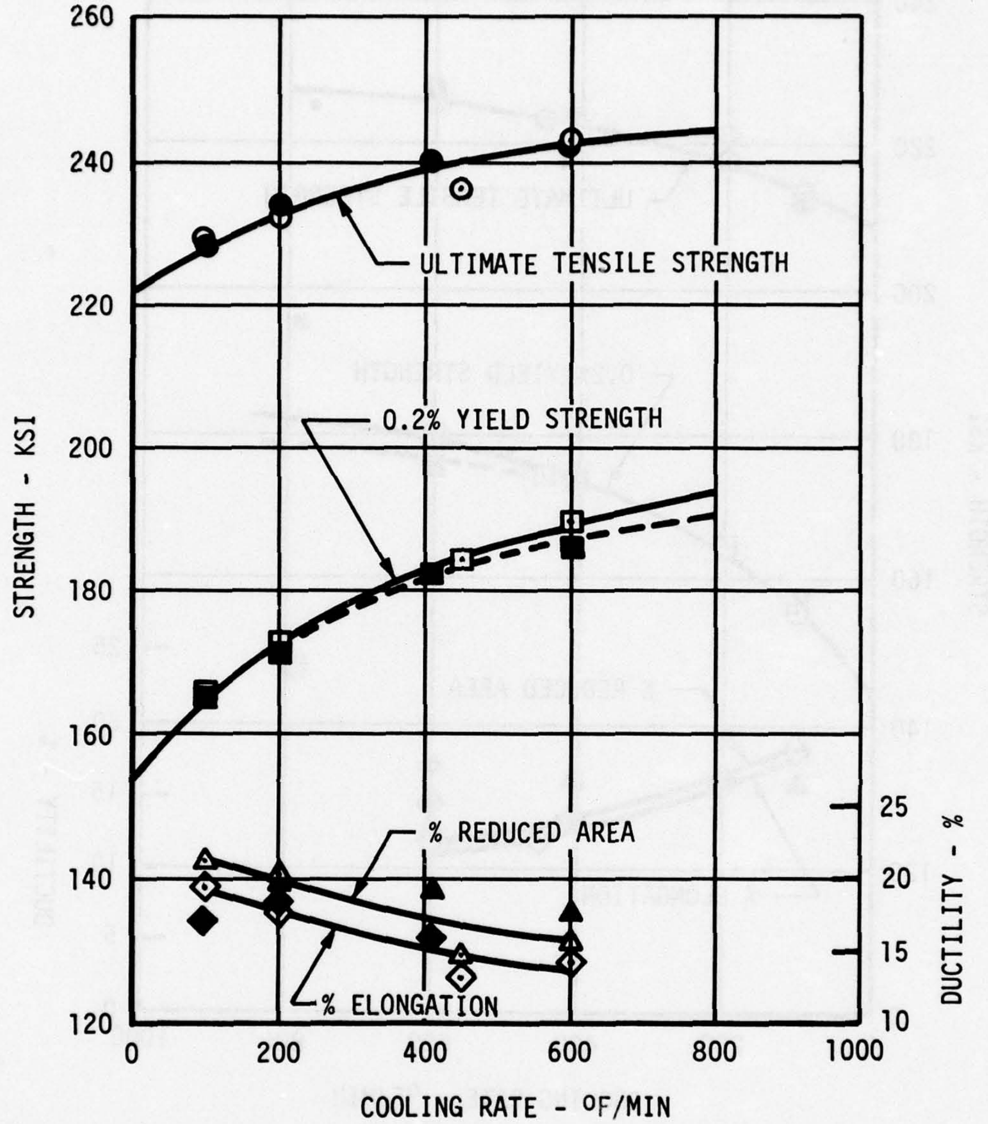


Figure 3. As-HIP René 95 Room Temperature Tensile Properties vs Cooling Rates from Two Solution Temperatures - Open Symbols T_s - 30°F (2100°F), Closed Symbols T_s - 60°F (2070°F)

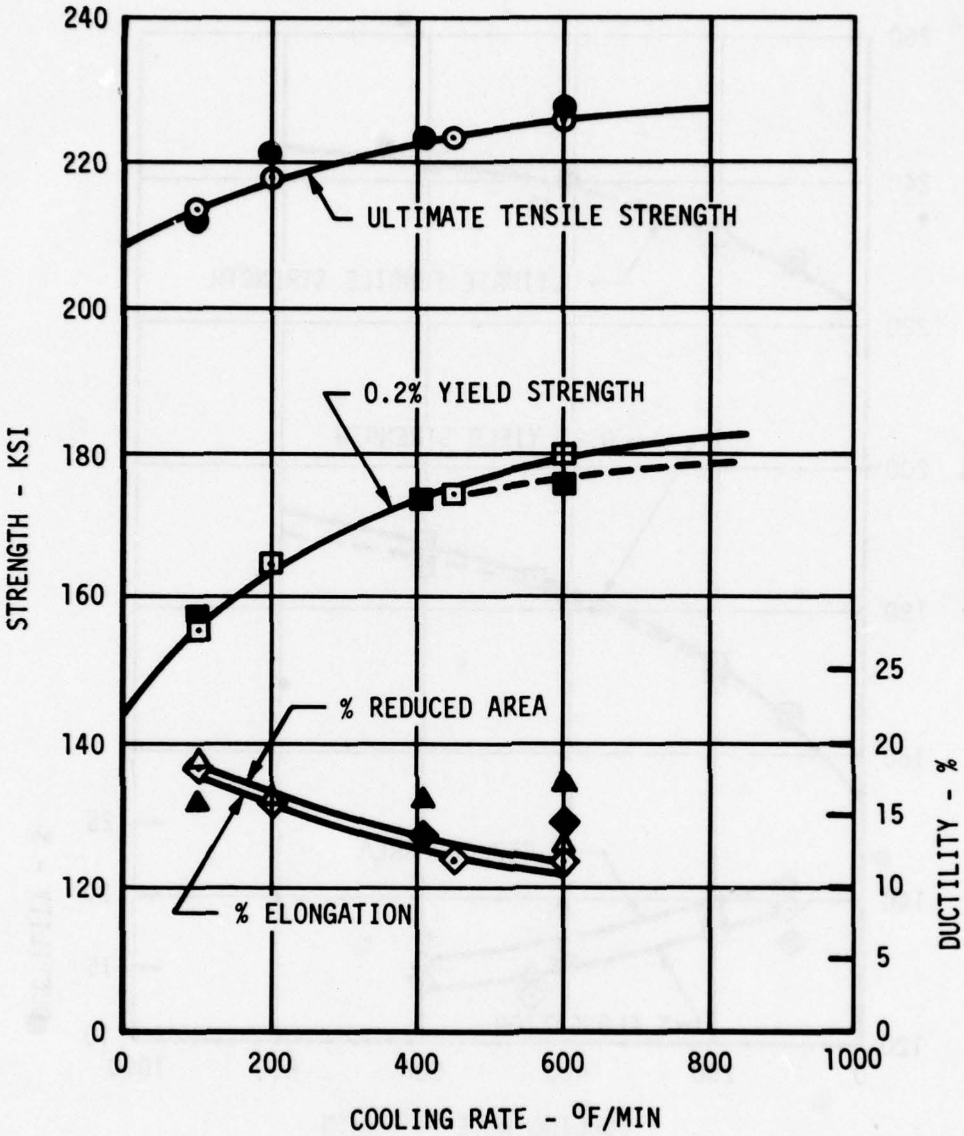


Figure 4. **As-HIP Rene′ 95 800°F Tensile Properties vs Cooling Rates from Two Solution Temperatures - Open Symbols T_s - 30°F (2100°F), Closed Symbols T_s - 60°F (2070°F)**

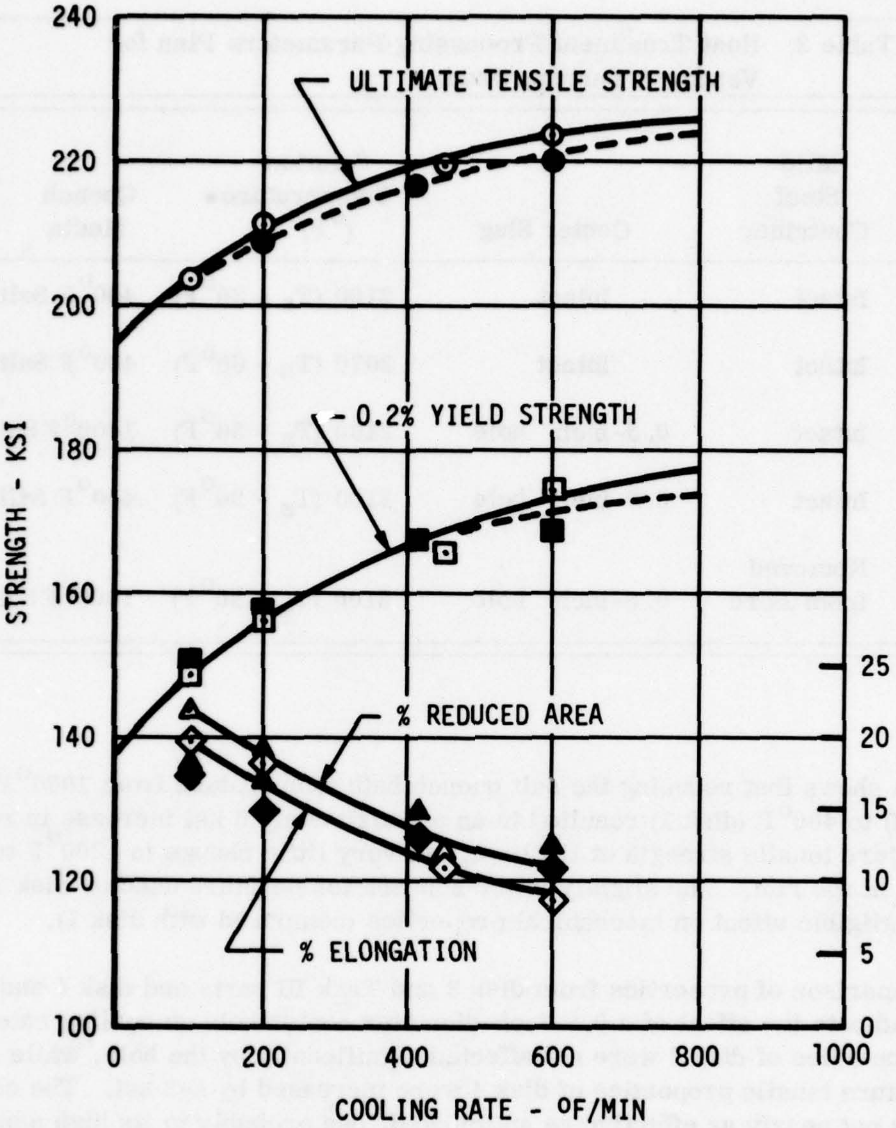


Figure 5. As-HIP Rene′ 95 1200°F Tensile Properties vs Cooling Rates from Two Solution Temperatures - Open Symbols T_s - 30°F (2100°F), Closed Symbols T_s - 60°F (2070°F)

Table 2. Heat Treatment Processing Parameters Plan for Vendor A Turbine Disks

Disk No.	Mild Steel Container	Center Slug	Solution Temperature (°F)	Quench Media
1	Intact	Intact	2100 (T_S - 30°F)	400°F Salt Bath
2	Intact	Intact	2070 (T_S - 60°F)	400°F Salt Bath
3	Intact	0.5-inch hole	2100 (T_S - 30°F)	1000°F Salt Bath
4	Intact	0.5-inch hole	2100 (T_S - 30°F)	400°F Salt Bath
5	Removed from Bore	0.5-inch hole	2100 (T_S - 30°F)	1000°F Salt Bath

The data shows that reducing the salt quench bath temperature from 1000°F (Task III) to 400°F (disk 1) resulted in an approximately 6 ksi increase in room temperature tensile strength at the bore, but very little change in 1200°F tensile strength at the rim. The slightly lower solution temperature used on disk 2 had a negligible effect on mechanical properties (compared with disk 1).

The comparison of properties from disk 3 and Task III parts and disk 4 and disk 1 indicate the effect of a 0.5-inch-diameter center hole on cooling rate. Bore properties of disk 3 were not affected significantly by the hole, while room temperature tensile properties of disk 4 were increased by 1-2 ksi. The center hole was not nearly as effective as anticipated, due probably to its high aspect ratio which undoubtedly restricted salt flow and heat transfer. A larger diameter hole may improve bore cooling rates, but would also eliminate all the test material required to monitor microstructure, density, and Thermally Induced Porosity of each disk. As expected, the rim (1200°F) properties were very similar to those obtained in disks heat treated without center holes (Task III and disk 1).

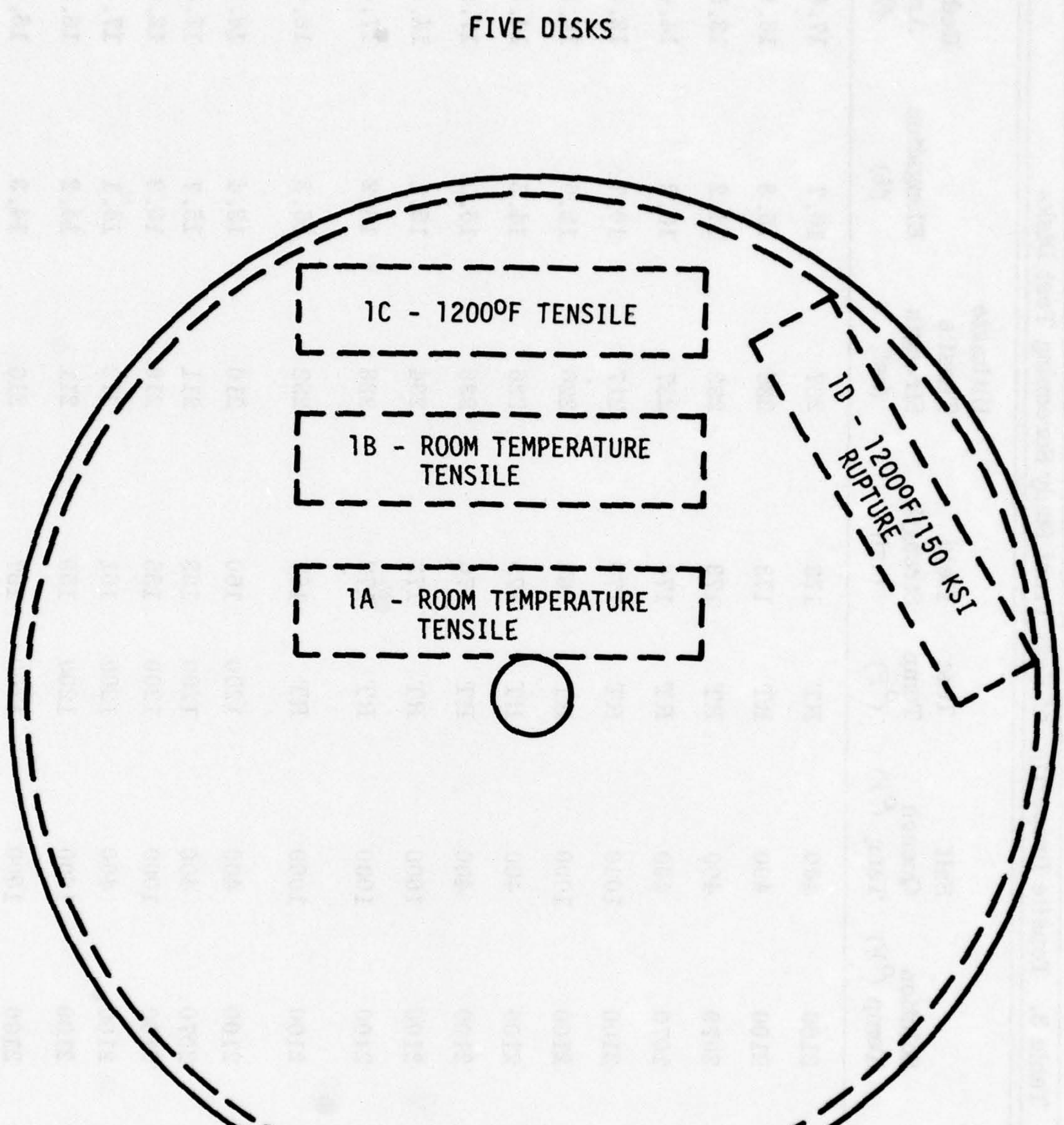


Figure 6. Revised Cut-Up Plan for Heat Treat Screening Study Disks

Table 3. Tensile Properties of Heat Treat Study Screening Test Disks

Disk No.	Specimen No.	Solution Temp (°F)	Salt Quench Temp (°F)	Test Temp (°F)	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)	Reduced Area (%)
1	1A	2100	400	RT	173	237	16.7	17.8
1	1B	2100	400	RT	173	236	15.8	16.0
2	2A	2070	400	RT	173	233	14.2	13.5
2	2B	2070	400	RT	174	237	16.2	14.4
3	3A	2100	1000	RT	170	217	10.7	12.0
3	3B	2100	1000	RT	168	226	12.6	14.5
4	4A	2100	400	RT	175	236	14.5	14.3
4	4B	2100	400	RT	176	239	16.3	17.5
5	5A	2100	1000	RT	172	234	15.1	14.9
5	5B	2100	1000	RT	172	236	16.2	17.0
Average Task III Results		2100	1000	RT	167	232	16.3	18.6
1	1C	2100	400	1200	160	210	13.4	16.2
2	2C	2070	400	1200	158	211	15.7	17.4
3	3C	2100	1000	1200	155	210	10.2	12.0
4	4C	2100	400	1200	161	212	14.1	17.4
5	5C	2100	1000	1200	159	211	14.2	16.2
Average Task III Results		2100	1000	1200	157	216	14.3	15.9

Table 4. Stress-Rupture and Sustained Peak Low Cycle Fatigue Properties of Heat Treat Study Screening Test Disks

Disk No.	Specimen No.	Solution Temp (^oF)	Salt Quench Temp (^oF)	Stress Rupture 1200°F/150 ksi Life (hr)	Stress Rupture 1200°F/150 ksi Elongation (%)	1200°F/145 ksi K_E=2 Life (hr)
1	1D	2100	400	33.7	1.5	724
2	2D	2070	400	27.9	1.7	
3	3D	2100	1000	75.8	3.3	
4	4D	2100	400	73.7 41.5	9.7 3.5	
5	5D	2100	1000	65.6	3.5	
Average Task III Results		2100	1000	68	5.2	600

The disk 5 measured the effect of machining the mild steel container off the bore region of a disk containing a 0.5-inch-diameter center hole. Compared to disk 3, bore yield strength properties were improved slightly. The suspiciously low UTS and ductilities of disk 3 made comparison of these properties with disk 5 data questionable. The stress rupture test results from all the disks were comparable to average Task III results, although the disks 1, 2, and 4 showed lower values in the first test. The sustained peak low cycle fatigue (SPLCF) test on disk 1 also yielded results comparable to Task III data.

The analysis of the data presented in Tables 2 and 3 thus indicates that, from a technical viewpoint, the heat treatment procedures used on disk 4 produced the most attractive mechanical properties. However, from an economic standpoint, the drilling of a center hole prior to heat treatment is undesirable. The added expense of drilling a center hole would be justified only if a significant improvement in mechanical properties was produced. Comparison of data from disks 1 and 4 suggests that the center hole has a minor effect on properties.

The heat treat processing of disks 3 and 5 did not provide a large enough increase in mechanical properties to justify the economic penalties associated with drilling a center hole and removing the HIP container from the bore region prior to heat treatment.

The improvement in bore properties effected by reducing the salt quench bath temperature from 1000°F (Task III parts) to 400°F (disk 1) was significant. Average room temperature yield and ultimate strengths were increased to 10-12 ksi above the T700 -2 σ minimum requirements. The 1200°F yield strength at the rim was increased slightly, but ultimate strength and ductility were slightly lower than those of Task III. Moreover, current (Task III) processing economics should not be adversely affected by simply reducing the salt quench bath temperature.

MODIFIED HEAT TREAT STUDY

At about the same time, under a separate General Electric effort the heat treat studies on T700 turbine disks had indicated that a more efficient and reproducible solution and quench process could be achieved by changing heat treat sources and procedures. The practice at Vendor A consists of solution treating in an air furnace followed by salt bath quenching. The temperature control and quench rates attained with this practice have been marginal in terms of producing the required mechanical properties. A modified practice involving solution treating in a salt bath followed by a salt bath quench (Vendor B) had been investigated. Results on T700 turbine disks indicated that improved mechanical properties can be reproducibly achieved with this practice at Vendor B. As a consequence of these recent studies, it was decided that the Task VI heat treat investigation be modified to include a detailed evaluation of Vendor B capabilities.

Fundamental cooling rate studies were thus initiated at Vendor B. A T700 turbine disk was prepared with thermocouples in the bore and rim regions to define cooling rates in these areas (Figure 7). Six heat treat sequences were completed, and cooling rate data accumulated. Each sequence began with a 1-hour solution treatment at T_s - 30^{o}F ±15^{o}F in a molten salt bath. The primary processing variables were quench bath temperature, quench bath agitation, and transfer time from solution bath to quench bath. Details are shown in Table 5.

Table 5. Heat Treat Sequence at Vendor B

Heat Treat Sequence No	Transfer Time (sec)	Quench Bath Temperature (^{o}F)	Agitation
1	10	1000	No
2	10	1000	Yes
3	60	1000	Yes
4	60	700	Yes
5	120	700	Yes
6*	10	700	Yes

*Disk fitted with 0.5-inch plates on top and bottom of rim area.

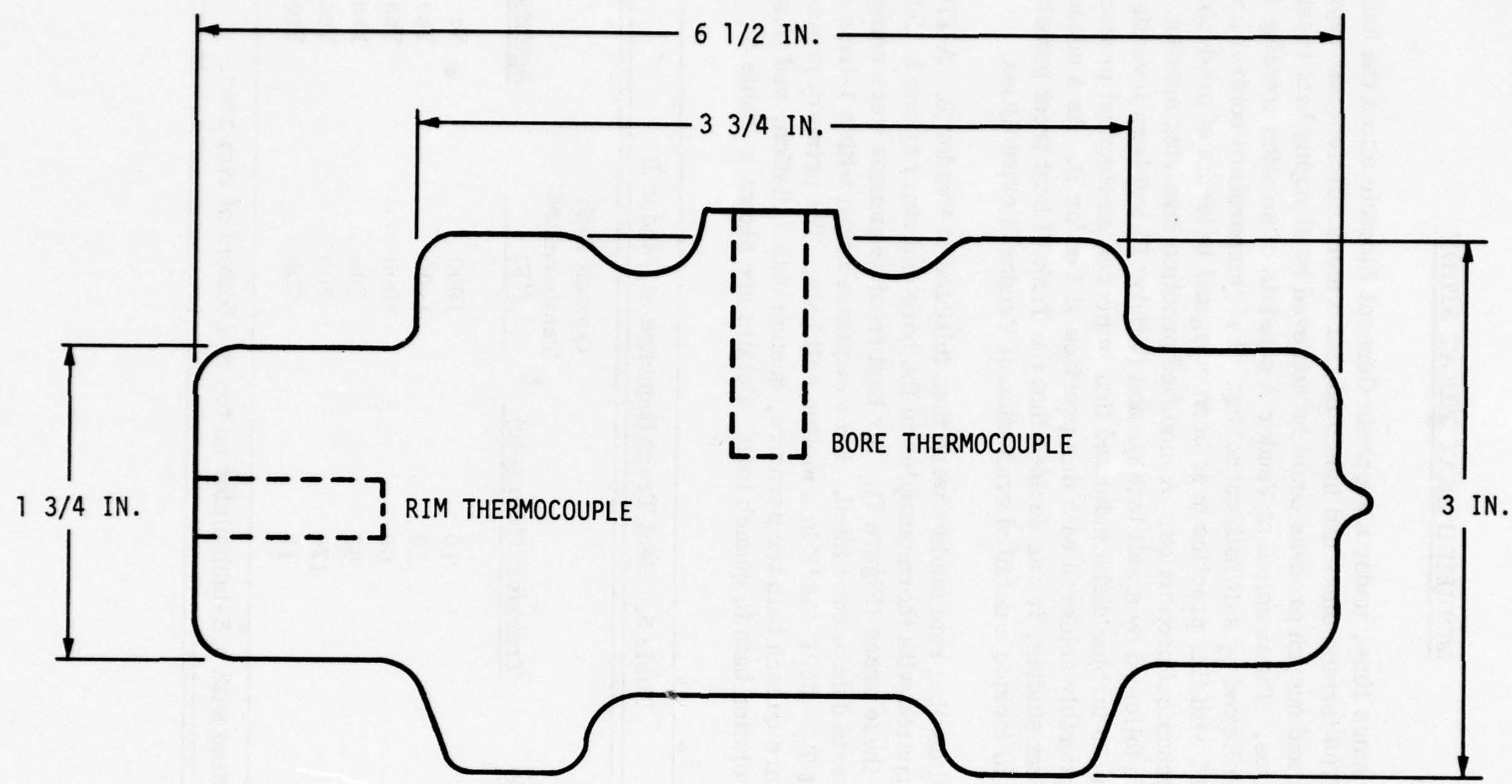


Figure 7. T700 Turbine Disk Used for Cooling Rate Studies at Vendor B Indicating Thermocouple Locations

Table 6. Heat Treat Sequence and the Cooling Rates

Heat Treat Sequence No.	Salt Bath Temp (^oF)	Transfer Time (sec)	Agitation	Cooling Rate (^oF/min) Bore	Rim
1	1000	10	No	185	360
2	1000	10	Yes	270	395
3	1000	60	Yes	220	365
4	700	60	Yes	280	440
5	700	120	Yes	390	430
6*	700	10	Yes	270	355

*Disk fitted with 0.5-inch plates on top and bottom of rim area.

Table 7. Heat Treat Sequence and Cooling Rates with Delayed Transfer Time

Heat Treat Sequence No.	Salt Bath Temp (^oF)	Transfer Time (sec)	Cooling Rate During Transfer (^oF/min)		Temp Prior to Quench (^oF)	
			Bore	Rim	Bore	Rim
3	1000	60	30	70	2060	2016
4	700	60	30	70	2055	2015
5	700	120	60	100	1998	1916

The temperatures were recorded as a function of time after removal from the solution salt bath using a Doric Digitrend 200 recorder. One time-temperature reading per second was tabulated from each thermocouple.

The cooling rate data was analyzed and the results are summarized in Tables 6 and 7.

A cooling rate of 250^o to 350^oF/minute is desired in the bore to achieve the room temperature 0.2% yield strength of 173 to 180 ksi. Also limiting the rim cooling rate to less than approximately 400^oF/minute should produce excellent 1200^oF strength properties without reducing ductilities below the desired minimums of 8% elongation and 10% reduction of area.

Quenching into 1000°F unagitated salt (sequence 1) produced an acceptable cooling rate in the rim, but the bore rate was somewhat lower than desired. Agitating the 1000°F salt and using a 10-second transfer time (sequence 2) increased the cooling rates in both regions to more desirable levels, although the measured value in the rim seems low when compared to the rate achieved in sequence 1.

Delaying the quench operation in sequences 3, 4, and 5 resulted in an air cool from T_S - 30°F during the delay followed by quenching from lower temperatures. The cooling rates given in Table 6 are those achieved after the disk was immersed in the salt bath. Although some scatter is apparent, the more representative rim cooling rates achieved after 60- or 120-second transfer times appear to be essentially equivalent to those effected after a rapid (10-second) transfer.

Table 7 shows the cooling rates during the delayed transfer of sequences 3, 4, and 5 along with the bore and rim temperatures just prior to salt bath quenching.

These significant reductions in temperature prior to quench make sequences including extended transfer times less desirable than those using rapid transfers.

The rim cooling rate in sequence 6 (Table 6) appeared to be reduced significantly by the 0.5-inch plates. The bore cooling rate was lower than anticipated, but a crack in the disk through the bore thermocouple hole which developed during this sequence may have affected results.

Analysis of the data in Tables 6 and 7 suggests that sequence 2 should provide the desired mechanical properties in both rim and bore regions, and this was next investigated by heat treating a disk for mechanical testing. In order to obtain a clearer relationship between cooling rate and mechanical properties, two additional disks were treated to the parameters shown in Table 8. In addition, a fourth disk was heat treated according to sequence 6 and evaluated to determine if addition of the rim plates does produce a better balance of bore and rim properties.

These four disks were sectioned per the cut-up plan of Figure 8. The tensile test results are presented in Table 9. Data from disks 1, 2, and 3 indicated the expected increase in strength with cooling rate (lower salt bath temperature), although the room temperature bore results were somewhat lower than expected. Ductilities at 1200°F decreased with increasing cooling rate and became marginal in disk 3. Comparing data from disks 1, 2, and 3 with the T700 requirements indicated that disks 1 and 2 would meet all requirements, while disk 3 would be marginal in room temperature ultimate tensile strength at the

Table 8. Heat Treat Sequence for Additional Disks			
Heat Treat Sequence No.	Salt Bath Temp (^{o}F)	Transfer Time (sec)	Agitation
1	1150	10	Yes
2	1000	10	Yes
3	850	10	Yes
4*	700	10	Yes

*Disk fitted with 0.5-inch plates on top and bottom of rim area.

bore and 1200^{o}F ductility at the rim. Disk 4 was quenched into a 700^{o}F salt bath with 0.5-inch steel plates on top and bottom of the rim area to reduce the cooling rate. Tensile data shown in Table 9 indicate that an excellent combination of high room temperature bore strength and 1200^{o}F rim strength was achieved without compromising 1200^{o}F ductility in the rim. The tensile properties of disk 4 would also meet the T700 requirements. The effect of salt bath quench temperature (cooling rate) on room temperature and 1200^{o}F tensile properties is illustrated in Figures 9 and 10. The improvements in room temperature ultimate tensile strength and 1200^{o}F ductility effected by using the 0.5-inch rim plates and a 700^{o}F salt bath quench are noteworthy.

Results of stress rupture testing at 1200^{o}F/150 ksi are presented in Table 10. All rupture lives met the specification requirement of 25 hours, but the ductilities were somewhat low. However, only disk 2 failed to meet the specification requirement of 2%.

Detailed Mechanical Property Evaluation

While the above data was being generated, a meeting was held with the Government personnel at this time to determine the future direction of the program. Since the current T700 production hardware uses -150 mesh screen powder, as opposed to the -60 mesh powder used in Tasks III and VI, it was agreed upon to conduct future heat treat study on these parts. It was further decided to use heat treat sequence with agitated salt bath temperature of $1000^{o}F$ (equivalent to disk 2 in Table 5) in further testing. This is also the heat treatment used in current production hardware.

Moreover, using the test results from the production hardware will eliminate the need of making extra hardware specifically for the heat treat study. The disks to study the reheat treatment behavior will,however, be separately heat treated.

Two turbine disks from the first batch of production hardware were evaluated per the cut-up plan of Figure 11. The tensile, stress rupture, sustained peak low cycle fatigue, and creep rupture test results are shown in Tables 11 through 15. The crack propagation test results are listed in Table 16. The test results are similar to those obtained in Task III and meet the engineering requirement for these properties. The slight discrepancy between the tensile properties could perhaps be the result of location within the quench tank.

Table 9. Tensile Results of Disks

Heat Treat Sequence No.	Room Temperature: Bore Specimen No.	Bore 0.2% Yield Strength (ksi)	Bore Ultimate Tensile Strength (ksi)	Bore Elong-ation (%)	Bore Reduced Area (%)	Mid-Bore Specimen No.	Mid-Bore 0.2% Yield Strength (ksi)	Mid-Bore Ultimate Tensile Strength (ksi)	Mid-Bore Elon ation (%)
1	1A	171	235	17.5	17.8	1B	175	238	15.2
2	2A	171	235	17.0	16.4	2B	177	239	15.8
3	3A	174	230	13.5	14.8	3B	179	240	15.4
4	4A	175	238	16.7	16.1	4B	176	239	16.4
T700 Minimum Requirements		163	225	10	12				

Table 9. Tensile Results of Disks at Vendor B

Room Temperature						1200°F Tensile				
	Mid-Bore					Rim				
educed Area (%)	Specimen No.	0.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elong-ation (%)	Reduced Area (%)	Specimen No.	0.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elong-ation (%)	Reduced Area (%)
7.8	1B	175	238	15.2	17.3	1C	160	216	16.5	17.9
						1D	161	217	12.9	14.9
6.4	2B	177	239	15.8	16.5	2C	170	217	9.8	9.3
						2D	165	214	12.1	13.7
4.8	3B	179	240	15.4	17.0	3C	172	224	10.1	11.6
						3D	167	216	8.6	11.2
6.1	4B	176	239	16.4	17.2	4C	166	219	12.8	14.0
						4D	168	222	13.1	12.0
2							153	203	8	10

2

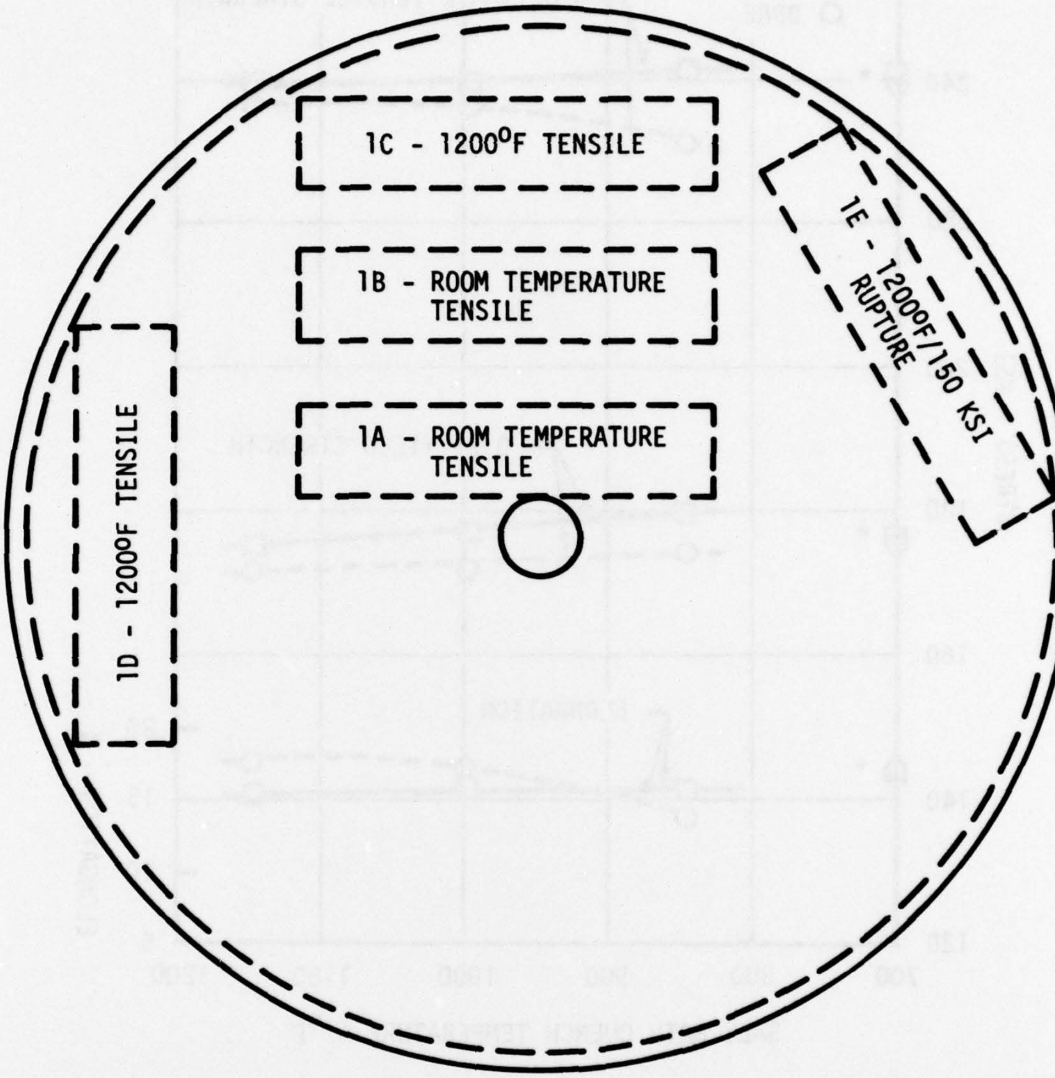
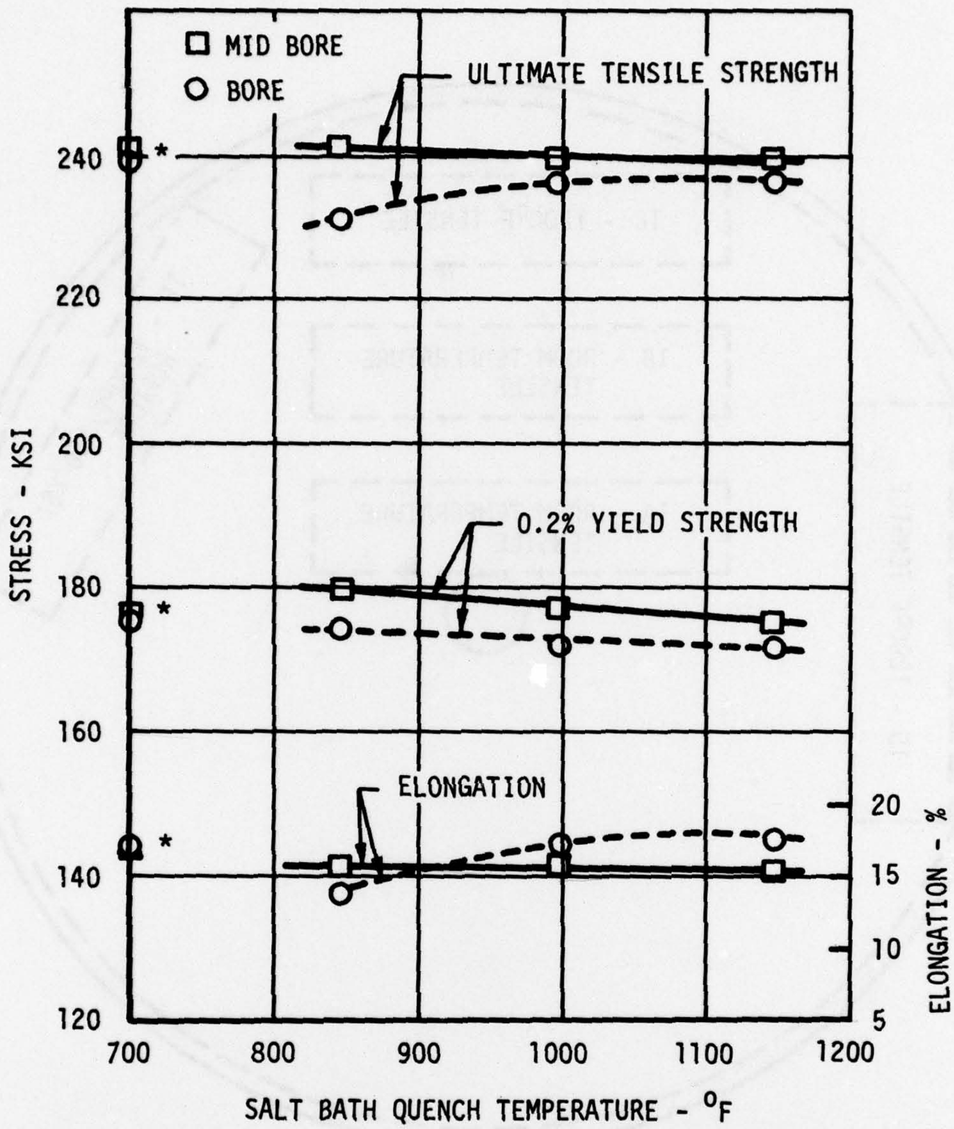
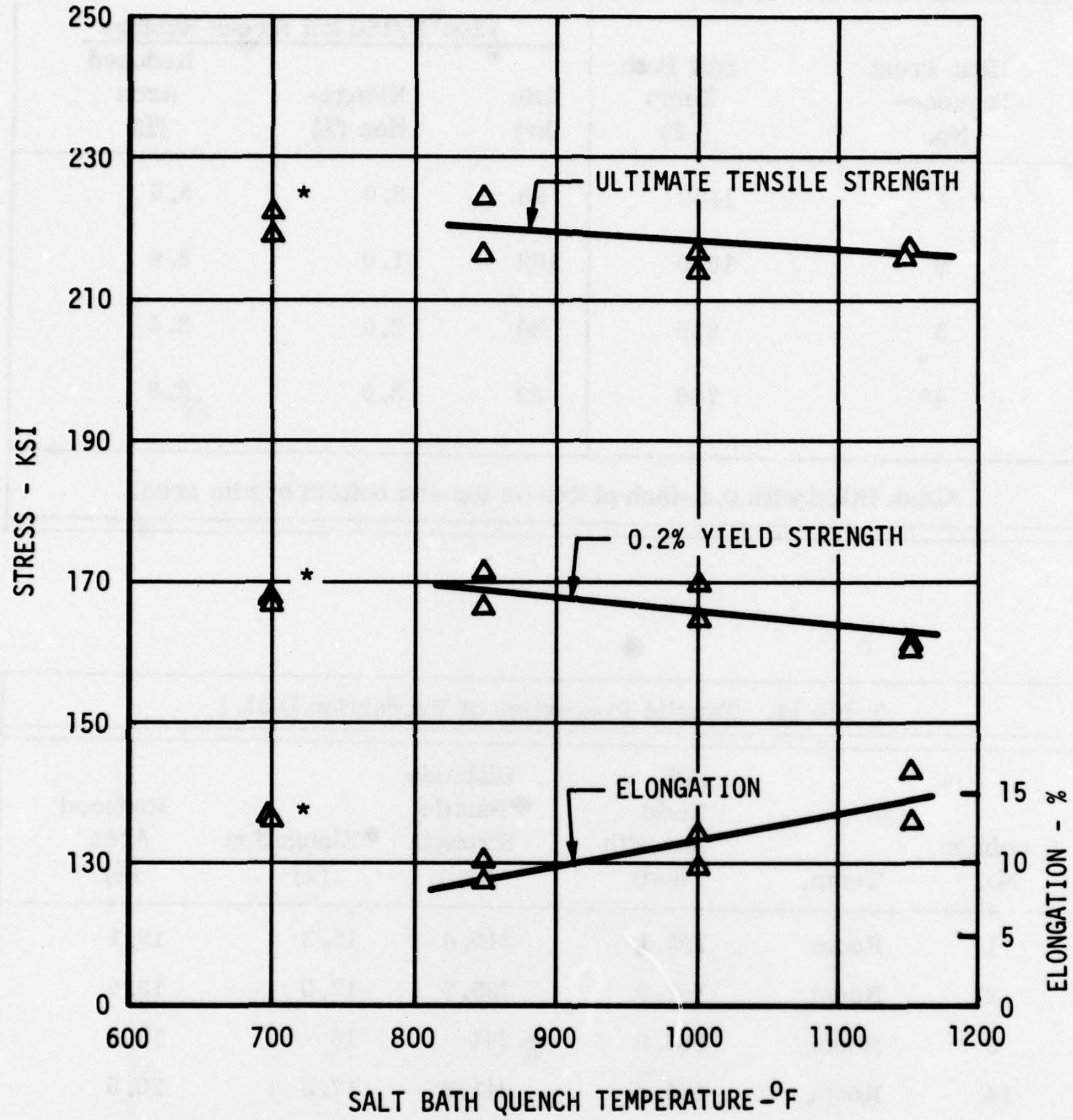


Figure 8. Revised Cut-Up Plan for Heat Treat Screening Study Disks



* Disk Quenched at 700^{o}F Had 0.5-Inch Plates Attached To Rim.

Figure 9. Room Temperature Tensile Properties of T700 Disks Heat Treated at Vendor B



* Disk Quenched at 700°F Had 0.5-Inch Plates Attached To Rim.

Figure 10. 1200°F Tensile Properties of T700 Disks Heat Treated at Vendor B

Table 10. Stress Rupture Results of Disks at Vendor B

Heat Treat Sequence No.	Salt Bath Temp (°F)	1200°F/150 ksi Stress Rupture Life (hr)	Elongation (%)	Reduced Area (%)
1	1150	98	2.6	5.5
2	1000	162	1.0	2.8
3	850	80	2.0	2.4
4*	700	89	3.0	2.8

*Disk fitted with 0.5-inch plates on top and bottom of rim area.

Table 11. Tensile Properties of Production Disk 1

Specimen No.	Temp.	.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)	Reduced Area (%)
1	Room	193.1	249.6	15.3	19.1
2	Room	181.3	235.3	12.5	13.8
3	Room	183.6	244	16	15.9
14	Room	174.5	241.3	17.3	20.5
4	1200°F	177.4	216.3	8.4	9.5
5	1200°F	166.2	215.3	12.0	16.8
6	1200°F	166.2	216.4	14.6	18.1
7	1200°F	162.2	214.9	16.3	19.1

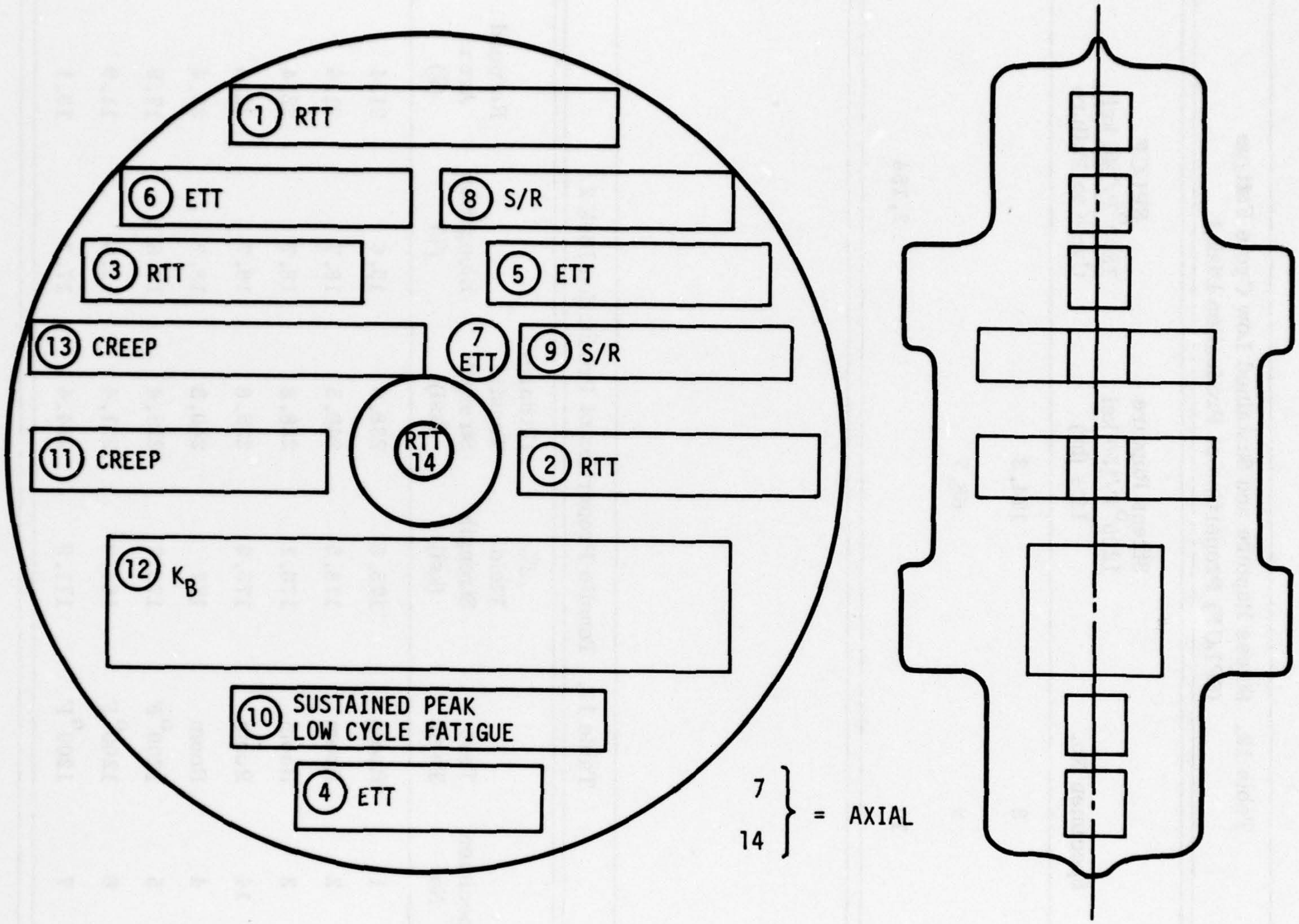


Figure 11. Cut-Up Diagram of T700 Disk

Table 12. Stress Rupture and Sustained Low Cycle Fatigue (SPLCF) Properties of Production Disk 1

Specimen No.	Stress Rupture $1200^{o}F/150$ ksi Life (hr)	SPLCF $1200^{o}F/145$ ksi Cycle to Failure
8	174.3	
9	68.7	
10		2,154

Table 13. Tensile Properties of Production Disk 2

Specimen No.	Test Temp	.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)	Reduced Area (%)
1	Room	175.5	238.6	15.6	21.4
2	Room	178.5	240.5	18.7	21.4
3	Room	176.1	238.8	18.7	22.4
14	Room	175.5	238.8	18.7	22.4
4	Room	177	240.3	18.7	23.4
5	$1200^{o}F$	173.7	225.4	15.6	17.9
6	$1200^{o}F$	164.2	221.4	12.6	11.9
7	$1200^{o}F$	171.9	224.4	17.2	19.1

Table 14. Stress Rupture and Sustained Peak Low Cycle Fatigue (SPLCF) Properties of Production Disk 2

Specimen No.	Stress Rupture 1200°F/150 ksi Hours	Stress Rupture 1200°F/150 ksi Elongation	SPLCF 1200°F/145 ksi
8	151.6	4.7	
9	144	7.8	
10			723

Table 15. Creep Results of Production Disk 2

Specimen No.	Test Temp. (°F)	Stress (ksi)	Time to .1% Creep (hr)	Remarks
11	1100	150	200	Test discontinued after 260 hours.
13	1100	150	80	Test discontinued after 240 hours.

Table 16. 1000°F Crack Propagation Results of Production Disk 2

Specimen No.	Max Stress (ksi)	Nominal Initial Fatigue Crack Length (in.)	Nominal Initial Fatigue Crack Depth (in.)	Residual Life (Cycles)
12	100	.066	.029	4578

A ratio = 0.95
Frequency = 20 cpm

Specimen precracked at room temperature.

RE-HEAT TREATMENT STUDY

This study was initiated to determine the possibility of salvaging any improperly heat treated disk by re-heat-treating with proper heat treatment.

Four turbine disks (-60 mesh powder) were used to study the effect of double heat treatment. Three of these disks were deliberately heat treated with a different heat treatment than the standard selected heat treatment of the fourth disk. The initial heat treatment on each of the disks is listed in Table 17. Each of the disks was then re-heat treated to the standard heat treatment schedule of 2085°F/1 hr/1000°F salt quench + 1600°F/1 hr + 1200°F/24 hr. The mechanical property testing was conducted on samples from each disk per the cut-up diagram of Figure 12. The tensile test results are shown in Tables 19 and 20.

As is evident from these results, the double heat treatment (even with a different initial heat treatment) produced similar tensile properties. The stress rupture properties are marginal and show differences from one disk to another, but this probably is due to data scatter rather than a specific effect of the heat treatment cycle. The sustained peak low cycle fatigue results, although showing scatter, far exceed the minimum requirement (300 cycles).

Table 17. Initial Heat Treatment of Turbine Disks

SA072	2085°F/1 hr/1000°F SQ + 1600°F/1 hr + 1200°F/24 hr
SA073	2025°F/1 hr/800°F SQ + 1600°F/1 hr + 1200°F/24 hr
SA074	2025°F/1 hr/1400°F SQ + 1600°F/4 hr
SA075	2105°F/1 hr/1000°F SQ + 1600°F/1 hr + 1200°F/24 hr

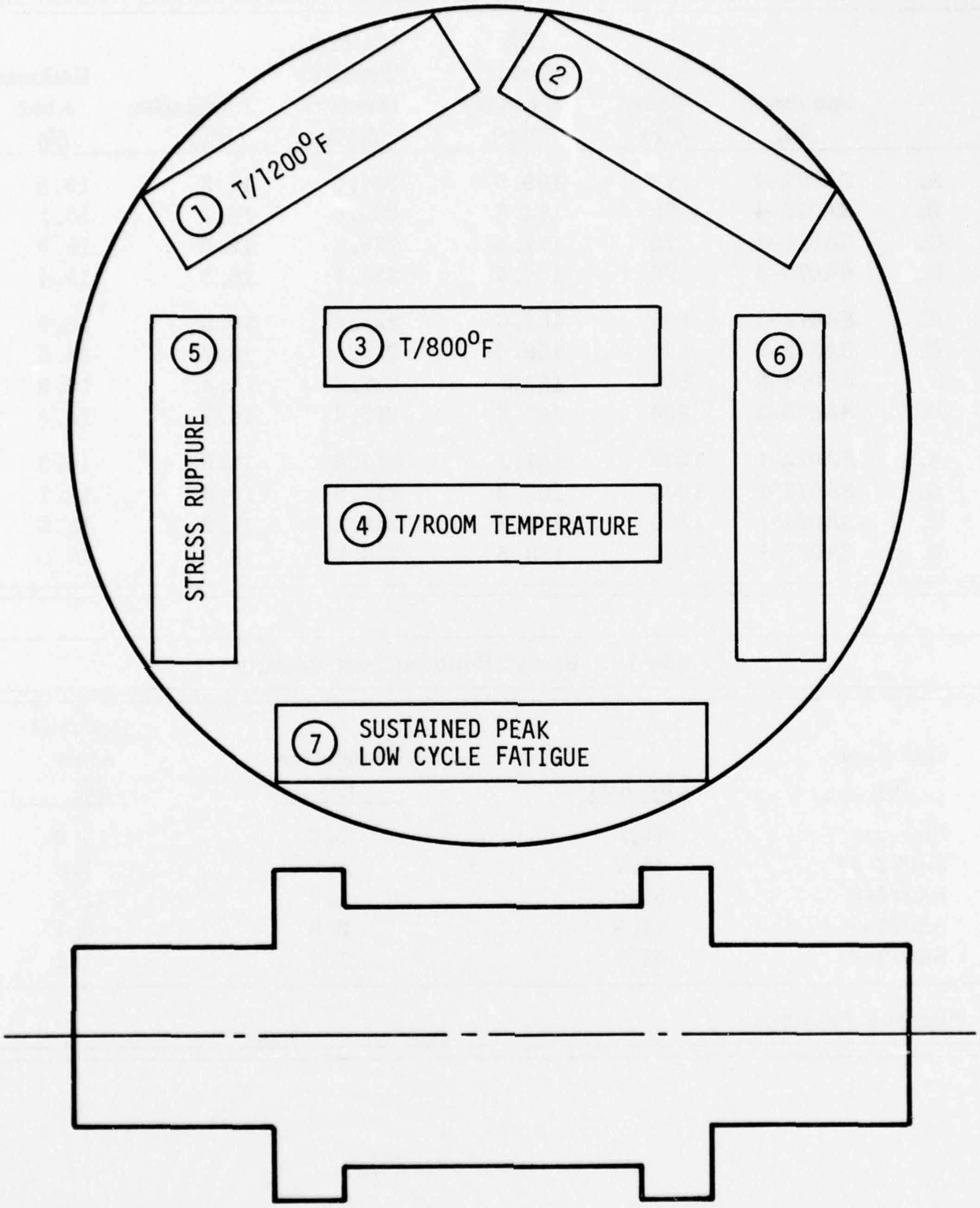


Figure 12. Cut-Up Diagram of Turbine Disk

Table 18. Tensile Property Results

	Specimen No.	Test Temp (°F)	.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)	Reduced Area (%)
A.	SA072-4	73	169.9	234.3	17.3	19.8
B.	SA073-4	72	174.3	235.6	15.7	15.1
C.	SA074-4	72	171.8	236.8	19.0	18.9
D.	SA075-4	72	172.5	234.1	16.3	15.4
A.	SA072-3	800	162.6	221.8	16.5	18.0
B.	SA073-3	800	159.5	217.3	15.7	14.5
C.	SA074-3	800	163.3	222.6	16.4	13.3
D.	SA075-3	800	162.7	217.4	14.7	14.8
A.	SA072-1	1200	167.1	217.4	11.5	14.3
B.	SA073-1	1200	166.2	217.5	10.0	11.7
C.	SA074-1	1200	167.1	218.2	11.2	13.5
D.	SA075-1	1200	163.5	216.9	9.2	10.9

Table 19. Stress Rupture Test Results

Specimen No.	Life (hr)	Elongation (%)	Reduced Area (%)
SA072-5	75.6	3.2	3.2
SA073-5*	41.7	2.7	1.6
SA074-5	85.0	1.6	1.2
SA075-5	11.9	2.9	2.4
SA073-2	58.7	1.9	1.2

*Radius Failures

Table 20. Sustained Peak Low Cycle Fatigue Test Results

1200°F/145 ksi Specimen No.	Life (cycles)
SA072-7	1468
SA073-7	2444
SA074-7	2377
SA075-7	3165

CONCLUSIONS

- A reliable correlation between cooling rates and mechanical properties has been generated, and the use of this correlation for tailoring heat treatment quench temperatures and part geometry has been demonstrated in René 95.
- Evaluation of disks with drilled 0.5-inch-diameter center holes indicated that the center hole has very little effect on resultant mechanical properties.
- Reducing the quench salt bath temperature from 1000°F to 400°F increased tensile properties significantly. Excessive transfer time delays reduced disk temperature at quench but did not significantly change the quench rate.
- Agitation of the quench salt bath improves the cooling rate achieved during heat treatment, thereby increasing resultant disk mechanical properties.
- Heat treatment of production disks using a 1000°F salt bath quench, rapid (10 seconds) transfer into the salt bath, and agitated salt bath resulted in fully acceptable mechanical properties.
- Effects of incorrect heat treatment, i.e., low solution temperature (down to T_S - 60°F), high solution temperature (up to T_S - 15°F), excessive 1600°F age, or low quench rate, can be completely eliminated and acceptable mechanical properties produced by application of a second, correct heat treat sequence.

DEPARTMENT OF THE ARMY

Applied Technology Laboratory
U.S. Army Research and Technology
Laboratories (AVRADCOM)
DAVDL-ATL-TSD
Fort Eustis, Virginia 23604

OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE ARMY
DOD-314

U.S. MAIL

THIRD CLASS